ACTIVE VIBRATION DAMPING IN A MACHINE TOOL

Description

The present invention relates to active vibration damping in a machine tool and specifically to both a method for vibration damping and an apparatus for performing the method.

During the mechanical machining of workpieces on machine tools, undesired vibrations are often arising. These may lead to dimensional inaccuracies and/or poor surface qualities of the workpiece.

Such vibrations may e.g. be caused by the machining process. For instance, the problem arises in milling tools that the individual cutting edges or teeth of the tool are successively engaged, thereby producing vibrations. These are e.g. expressed as chatter marks on the surface of the workpiece. However, they also lead to vibrations of the constructional elements of the machine tool itself.

In dynamic machine tools, e.g. portal-type or double-column milling machines or the like, vibrations may additionally be caused by the movements of the individual constructional elements or subassemblies of the machine tool itself. The short machining times require very fast traveling speeds of the individual spindles, supports, or similar subassemblies. Furthermore, with workpieces that are to be manufactured with very small radii, the path of the tool or the workpiece has to be changed within very short periods of time in order to realize the desired changes in curvature or direction. In this process the travel speeds in the axes must be so fast that these effect intermittent loads on the machine tools. Vibrations are also caused thereby.

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2 It has turned out to be very disadvantageous when the excitation of the vibrations

3 coincides with the natural frequency of the machine tool. Such undesired

4 frequencies may be due to both the machining process itself and the dynamic

5 process of the machine tool and the components thereof. The result may be an

6 escalation with particularly large dimensional deviations and poor surface qualities.

7

8 It is known from the prior art that such problems can be minimized in that the

9 machine tools are designed to be as stiff as possible and have no natural

10 frequencies in the low frequency range, if possible. Apart from the manufacturing

11 costs for such machine tools, it is not always possible to avoid or suppress the

12 occurrence of said undesired vibrations.

13

14 Furthermore, the prior art already discloses machine tools that as guide elements

15 comprise so-called "hydrostatic guides". These have e.g. a planar functional surface

16 in one component while a pocket with oil flowing therethrough is incorporated into

17 the other tool. The pocket is defined by lateral webs forming a gap with respect to

18 the other component, with oil passing through said gap.

19

20 Hence, a sliding of the two components on one another by means of the oil film is

21 possible by corresponding pressure application of the oil contained within the

22 pockets.

23

24 With an increasing load the gap decreases accordingly. The oil pressure is

25 correspondingly increased by mechanical measures in the prior art in order to

26 absorb this additional load. When the load decreases, the gap will increase

27 accordingly. The oil pressure in the pocket will then be reduced. Thus, the prior-art

28 solutions have the effect that the width of the gap (which means its free cross-

29 section of flow) is kept as constant as possible. This has the effect that vibrations of

1 the individual components of constructional elements/subassemblies need not be

2 taken into account.

3

4 It is thus possible to produce utmost stiffness in hydrostatic guides. To this end at an

5 increased load, the pressure of the oil fed into the pocket is increased to such an

6 extent that, despite the gap being smaller due to the higher load, a larger volume

7 flow is pressed through the narrowed gap. However, the increase in pressure of the

8 supplied oil is not sufficient to correct an increased load such that the gap assumes

9 the same size again within a finite period of time. Hence, the increased load leads to

10 a change in the gap that is permanent – though small because of the large volume

11 flow. The known regulation adapts the pressure to the load of the pocket, thereby

12 increasing the stiffness of the guide. The gap, however, changes because of

13 different loads.

14

15 It is the object of the present invention to provide a method for vibration damping in a

16 machine tool and an apparatus suited therefor, which permits the damping of arising

17 vibrations while being of a simple construction and usable in an easy and

18 operationally reliable way.

19

20 According to the invention this objet is achieved by the features of the two

21 independent claims; the sub-claims show further advantageous developments of the

22 invention.

23

24 Hence, according to the invention, the oil pressure in the pocket is regulated in

25 response to the loads arising in the hydrostatic guide.

26

27 Thus, the invention permits active vibration damping in the machine tool by means of

28 the hydrostatic guides. The oil pressure in the individual pockets is here regulated

29 such that vibrations arising in the machine tool are actively dampened.

1

2 With an active control of the volume flow and a constant measuring of the gap size,

3 the volume flow can be regulated according to the invention such that upon a change

4 in load the first resulting change in the gap is corrected within a finite period of time

5 such that the gap reassumes its original dimension despite the increased load, e.g.

6 with the help of a PID controller. Measured variable is the gap, manipulated variable

7 the volume flow, which is regulated in response to the load such that the gap will

8 reassume a constant dimension within a finite period of time upon changes in load.

9 Instead of a measurement of the gap size, the pocket pressure can also be used as

10 an input signal because it is possible to determine for a given pocket geometry at a

11 constant gap dimension for different loads on the guide which volume flow is

12 required at which pressure to absorb different loads at a constant gap dimension.

13 The volume flow is always regulated such that it coincides with a pressure

14 corresponding to a constant gap dimension. To this end the volume flow can be

15 regulated, for instance, via a proportional valve as shown in Fig. 2.

16

17 According to the invention it is also possible to regulate the oil flow by means of the

18 width of the gap.

19

20 Hence, according to the invention there is a relationship between the oil pressure in

21 the pocket and the oil volume flow exiting through the gap. As the disturbance

22 variable, the load is caused by the forces arising at the respective frequencies.

23 These form the corresponding disturbance. Without any external action the pressure

24 in the pocket as well as the volume flow would change accordingly, as is also known

25 in the prior art, in dependence upon the load arising, resulting in the corresponding

26 gap width. The undesired vibration behavior will then follow from these very

27 processes. It is possible by actively varying the pressure and/or the volume flow, as

28 intended according to the invention, to keep the gap width constant on the one hand

29 and to dampen undesired vibrations on the other hand.

1

2   Hence, it is possible according to the invention to regulate either the oil flow into the

3   pocket or the oil volume in the pocket. Both operations are carried out by a

4   superposed control which as the measured variable uses e.g. the oil pressure in the

5   pocket or the width of the gap as a basis.

6

7   It goes without saying that according to the invention individual pockets of the

8   hydrostatic guide and also all pockets of all hydrostatic guides of a whole machine

9   tool or a whole system can be controlled.

10

11   According to the invention either distance sensors or pressure sensors can be used

12   in the individual pockets for exactly sensing the actual state in the respective pocket.

13   It is thus possible via very fast control valves to determine and regulate the volume

14   flow of the oil into the individual pockets accordingly.

15

16   It is particularly advantageous when a pressure reservoir is provided in front of the

17   respective control valve to provide an adequate amount of oil at a high pressure for

18   the control.

19

20   The vibration damping action according to the invention can also take other data as

21   a basis for the invention in a preferred way. For instance, it is possible to provide

22   further sensors, e.g. acceleration pickups that are fastened to other locations of the

23   machine tool.

24

25   It is e.g. possible to arrange acceleration pickups at the lower end of the Z-axis of a

26   portal type machine. It is thereby e.g. possible to actively suppress, for instance, an

27   undesired pendulum movement (vibration) in the Z-axis.

28

1   A second essential aspect of the invention is the simultaneous consideration of

2   several pockets in one control unit (of a controller). The further solutions have tried

3   to make the guide as stiff as possible by controlling the pockets separately and

4   independently. In the invention all pockets that support a machine element, e.g. the

5   machine table for the workpiece or the Z-axis of the portal type machine, are taken

6   into account at the same time and controlled such that the machine element is

7   supported without any vibrations on the whole and almost in an infinitely stiff way,

8   and/or vibrations originating from the machine element, which are excited by the

9   machining or the dynamic traveling movement of the machine, are actively damped

10 by adaptation/modulation of the pocket pressures.

11

12 In a further variant of the invention it is thus possible to sense all status data (gap

13 width and/or oil pressure or further data) of the individual pockets of the individual

14 hydrostatic guides or supports of the machine tool in the vibration damping control

15 according to the invention. Furthermore, since the movement sequence of workpiece

16 and tool and thus the movements of the individual axes of the machine tool are

17 known in addition, the control unit according to the invention can predetermine the

18 resulting accelerations and the resulting dynamic loads of the individual pockets of

19 the individual hydrostatic guides. The loads arising can be compensated actively by

20 a corresponding control of the oil pressure in the individual pockets before said

21 loads lead to changes in the gap sizes within the pockets. This means that the

22 control unit according to the invention sets the oil pressure or oil volume actively in

23 an exact way such that the occurrence of undesired vibrations is avoided from the

24 start. The additional load resulting from the movement processes and accelerations

25 can thus be absorbed without any change in the gap.

26

27 Furthermore, it is possible according to the invention to regulate the oil pressure in

28 the pockets such that with a constant vibration behavior of the machine tool or the

29 components or machine elements of the machine tool the occurrence of vibrations is

1 actively suppressed. This means that e.g. the oil pressure in the individual pockets is

2 actively changed such that the natural vibration behavior of the machine tool does

3 either not influence the gap widths or gap sizes or the arising vibrations can be

4 dampened very rapidly. In the first case the occurrence of undesired vibrations is

5 avoided from the start.

6

7 According to the invention it may also be taken into account that in some concepts of

8 machine tools the behavior of the individual axes is overlapping. In a portal type

9 machine a pendulum movement of the Z-axis, for instance, has an effect on the

10 guide in Z-direction and on the guide in Y-direction. Hence, an active compensation

11 for a pendulum movement regulates the pressure in the pockets of both guides (Y-

12 direction and Z-direction) according to the invention. Hence, it is of essential

13 importance according to the invention that in program-controlled machines the

14 sequence of movement of the individual axes through the program, e.g. the milling

15 program on a milling machine, is known. On the basis of the program it is possible to

16 determine the movement sequence of the individual machine elements and to

17 calculate the resulting changes in load in the individual pockets supporting the

18 respective machine elements. With the help of this calculation the volume flows into

19 the pockets supporting the respective machine element can be pre-controlled such

20 that the resulting changes in the pocket pressures compensate the changes in load

21 resulting from the machine program and keep the gap dimensions constant in all

22 pockets. The necessary calculations can be carried out online in the case of

23 powerful machine controls, i.e. during execution of the programs. The machine

24 control unit will then control the travel movement of the machine axes and, at the

25 same time, the volume flows into the pockets of the hydrostatic guides.

26

27 According to the invention there are different possibilities of solution with respect to

28 the apparatus. Apart from the use of control valves, it is also possible to vary the

29 respective work volume of the pocket itself. This can e.g. be carried out by

1   piston/cylinder units or by corresponding piezoelectric elements. These show a very

2   rapid response and lead to a change in the work volume of the pocket and thus to a

3   change in pressure of the oil positioned in the pocket.

4

5   Furthermore, it may be of advantage when in machine elements which are deformed

6   because of the sequence of movements, e.g. a lateral acceleration process of the Z-

7   axis of a portal type machine, on account of their finite stiffness, the above-

8   mentioned pre-control is overridden, i.e. the gap sizes of the pockets supporting the

9   machine element are changed in a targeted way such that the machining

10   inaccuracies caused by the deformation of the respective machine element are

11   minimized on the machine.

12

13   According to the invention it has turned out to be of particular advantage when the

14   oil pressure and/or the oil flow and/or the oil volume of several pockets of several

15   hydrostatic guides of a machine tool are regulated by means of a joint control unit. It

16   is thus particularly possible to actively dampen vibrations of components, be it

17   components of the machine tool or workpieces. The control according to the

18   invention can here consider constructional conditions. The vibrations arising may

19   either be vibrations of the components that are excited from the outside, or these

20   may be vibrations of the component or the workpiece itself. Hence, according to the

21   invention this opens the possibility of either measuring, and correcting in real time,

22   such vibration behavior or of controlling such behavior accordingly and of taking into

23   account the values stored in a memory under working conditions of the machine tool

24   causing the occurrence of vibrations and of adapting the control accordingly.

25

26   According to the invention, it is particularly advantageous when the individual

27   pockets are controlled independently of one another. Hence, the corresponding

28   hydrostatic guides can be taken into account with respect to their natural behavior. It

1   can also be taken into account which forces and vibrations act on the individual

2   hydrostatic guides independently of one another.

3

4   Hence, the invention opens the possibility of either calculating the arising vibrations

5   and of making the values available in a memory, or of measuring the vibrations in

6   real time and of processing them accordingly by means of the control unit.

7

8   According to the invention it is thus possible to support a machine element in a

9   highly stiff way because the control unit according to the invention can compensate

10   manufacturing inaccuracies, dimensional inaccuracies, or the like, by way of a

11   corresponding control. This also opens the possibility of using hydrostatic guides

12   that are by far less precise and thus less expensive and of realizing their precise

13   operation by means of the control unit according to the invention. Hence, vibrations

14   excited from the outside as well as natural vibrations can be dampened actively by

15   the control unit of the invention counteracting and damping the vibrations of the

16   machine element actively by a corresponding control of the individual pockets.

17

18   According to the invention it is further possible to compensate dimensional

19   inaccuracies, particularly with respect to the gap heights of the hydrostatic guides

20   and other flaws or defects of the guideways. For instance, each of the guideways of

21   the hydrostatic guides is thereby measured on a measurement table (e.g. granite

22   stone). The corresponding values are stored in a memory which can be accessed by

23   the control unit. Hence, during the machining process the control unit according to

24   the invention can access the memory. The unit compares the stored values with the

25   set values and can react immediately, e.g. in response to a distance coordinate of

26   the hydrostatic guide, to compensate the dimensional deviations or defects or flaws

27   of the hydrostatic guide. A hydrostatically supported machine table, for instance,

28   would then travel by means of the control unit according to the invention along a

29   theoretically ideal guideway and not, as is known in the prior art, follow the slight

1 flaws or deviations of the guideway. Slight lateral displacements, e.g. of the guide

2 table relative to the guideway, or slight tilting that might arise as a flaw can thus be

3 compensated according to the invention in that the table is displaced or tilted to

4 counteract such a flaw. The result is the movement along the theoretically ideal

5 guideway. In response to precision and rapidness of the control unit of the invention,

6 the resulting path of the table or component of the machine tool can thus be

7 approximated, as closely as desired, to an ideal movement path.

8

9 On the whole, the present invention has the effect that the use of the method

10 according to the invention will achieve such a high degree of precision that is not

11 possible in known machine tools or can only be realized at very great costs.

12

13 It goes without saying that the flaw compensations described according to the

14 invention can also compensate thermally created flaws of the guideways.

15

16 The present invention is not restricted to longitudinal hydrostatic guides. Rather, the

17 method according to the invention can be used for any hydrostatically supported

18 machine element.

19

20 The present invention shall now be described with reference to embodiments taken

21 in conjunction with the drawing, in which:

22

23 Fig. 1 is a perspective simplified illustration of a machine tool for using the vibration

24   damping according to the invention;

25

26 Fig. 2 is a partial sectional view of a hydrostatic guide according to the invention, in

27   a schematized illustration;

28

29 Fig. 3 is a view, similar to Fig. 2, of a further embodiment of the hydrostatic guide.

1

2 Fig. 1 is a schematic perspective view illustrating a machine tool with a machine bed

3 12 having supported thereon a portal 13. A table 14 which can carry a workpiece

4 (not shown) is displaceably supported on the machine bed 12. The table 14 is

5 horizontally displaceable.

6

7 The portal 13 supports a carrier 15 which is also displaceable in horizontal direction

8 relative to portal 13. The axis of movement of the carrier 15 is arranged at a right

9 angle to the axis of movement of table 14.

10

11 A spindle 17 which is rotatable and carries a tool 18 is supported on the carrier 15 in

12 a vertically displaceable manner by means of a component 16.

13

14 An illustration of further details, e.g. of the drive units, or the like, is here not needed

15 because these are known from the prior art.

16

17 Table 14 is supported on the machine bed 12 by means of a hydrostatic guide 8 (see

18 Figs. 2 and 3), which is not shown in detail. Likewise, the carrier 15 is supported on

19 the portal 13 by means of a hydrostatic guide. The same applies by analogy to the

20 support of component 16 on carrier 15.

21

22 Each of Figs. 2 and 3 is a simplified sectional illustration of the hydrostatic guides 8

23 that serve to support a first component 9 on a second component 10 in a

24 displaceable way.

25

26 The hydrostatic guide 8 comprises a corresponding pocket 1 which is acted upon

27 with oil via a supply channel 7. The pocket 1 is defined by webs 11 which with

28 respect to the surface of the second component 10 form a gap 3 through which oil

29 exits.

1

2 The supply channel 7 is connected to a supply line 6 for oil.

3

4 In the embodiment shown in Fig. 2, a control valve 4 is provided that is arranged

5 upstream of a pressure reservoir 5. Downstream of the control valve 4, there is

6 shown a line 2 which is connected to the supply channel 7. It is possible by operating

7 the control valve 4 to regulate the oil pressure in the pocket 1 and the oil volume

8 introduced into pocket 1.

9

10 Fig. 3 shows a modified embodiment which can also be combined with the

11 embodiment shown in Fig. 2. In this case a piezoelectric element 19 by which the

12 volume of pocket 1 can be varied is schematically shown in the area of pocket 1. The

13 oil pressure in pocket 1 will rise by changing the volume by means of the

14 piezoelectric element 19, resulting in an increased oil volume flow through gap 3. An

15 increased load on the first component 9 can thereby be compensated.

16

17 The present invention is not limited to the illustrated embodiment. Rather, many

18 alterations and modifications are possible within the scope of the invention. The

19 invention also relates to hydrostatic shaft bearings.